Chapter 4
Determining Flood Flows by Frequency Methods

4-1. Overview

a. Measures of flood severity. The majority of flood damage reduction studies require the evaluation of peak discharge, often used as the main measure of flood severity. Other variables, such as the total runoff volume, may also be critical for certain studies. Flood studies require frequency estimates in order to judge the performance of proposed flood damage reduction projects. The development of peak discharge-frequency relationships for a catchment is an important part of flood evaluation for Corps studies. This relationship is linked with elevation-discharge data and with elevation-damage data using risk-based analysis procedures to arrive at estimates of expected annual damage for with- and without-project conditions.

b. Discharge-frequency estimates. Some degree of uncertainty exists in all discharge-frequency estimates. This uncertainty results from insufficient information. The more data available, the better the estimate of discharge-frequency. In a typical flood damage reduction study, a certain amount of known (gaged) data will exist, but some of the study area may have no gaged data. Consequently, a combination of gaged and ungaged techniques are often used for the hydrologic analysis.

4-2. Analysis for Gaged Areas

The development of discharge-frequency relationships at gaged locations is a well-documented process involving statistical analysis of annual peak discharges. Figure 4-1 shows the results of a statistical analysis of recorded data. The analysis requires an adequate length of stream gaged record, with the data being both homogenous and of good quality. References (Water Resources Council 1982, EM 1110-2-1415) give the complete technical detail necessary for statistical analysis of stream-gaged records.

a. Record length.

(1) Although opinions vary as to a minimum record length, at least ten years of data is generally recommended. As one might suspect, ten years of data would seem a very limited amount to estimate, say, the 1-percent chance exceedance frequency peak discharge. The absence of significant peak discharges, such as during an extensive drought, or the occurrence of several floods during this short period would result in a poor estimate of the flood-frequency relationship. A "rule of thumb" suggests that the rarest flood that can be predicted with a reasonable level of confidence is about double the period of record. A 5-percent chance exceedance frequency (20-year) flood would be the largest for 10 years of data.

(2) Major changes in the estimates of return periods of rare floods are not unusual as one acquires more data. Obviously, the longer the period of gaged data, the more confidence one could have in the final result. Thirty or more years of data is generally desired for "good" statistical frequency estimates. Even if one has a lengthy record, comparison and modification of the relationship derived by statistical means is often made. This effort may involve regional studies considering nearby gages, and hypothetical floods developed with hydrologic models.

b. Record homogeneity/quality. As the record becomes lengthy, one becomes more concerned with changes in the catchment upstream of the gage, potentially resulting in a non-homogenous data record. Typical examples of non-homogenous records often cited are the urbanization of the land upstream of the gage, or the installation of a major reservoir. These man-induced changes result in different runoff volumes, hydrograph shapes, and peak discharges for similar storms. If significant changes occur during a period of recorded data, adjustments to or separation of the record is necessary. Quality of the data should also be considered, as stream gaging techniques can only estimate the total discharge during flood events. The USGS, the source for most gage data, evaluates the quality of its data at each of its gaged sites. A description of "Excellent" means that 95 percent of the daily discharges are within 5 percent of the true value, "Good"--within 10 percent, "Fair"--within 15 percent, and "Poor"--less than "Fair." Accuracy and confidence level are much lower for a statistical analysis of gaged data with a poor or fair rating than data with a good or excellent rating.

c. Need for ungaged techniques. When statistical analyses of gaged data are performed for a long-record station, the resulting estimate of discharge-frequency is considered the most accurate of any technique available. However, this relationship is only valid at the gage, and not at points significantly removed from the site. Thus, ungaged methods are almost always required along with statistical methods. Besides giving a precise estimate of discharge-frequency, gaged data allow one to compare the

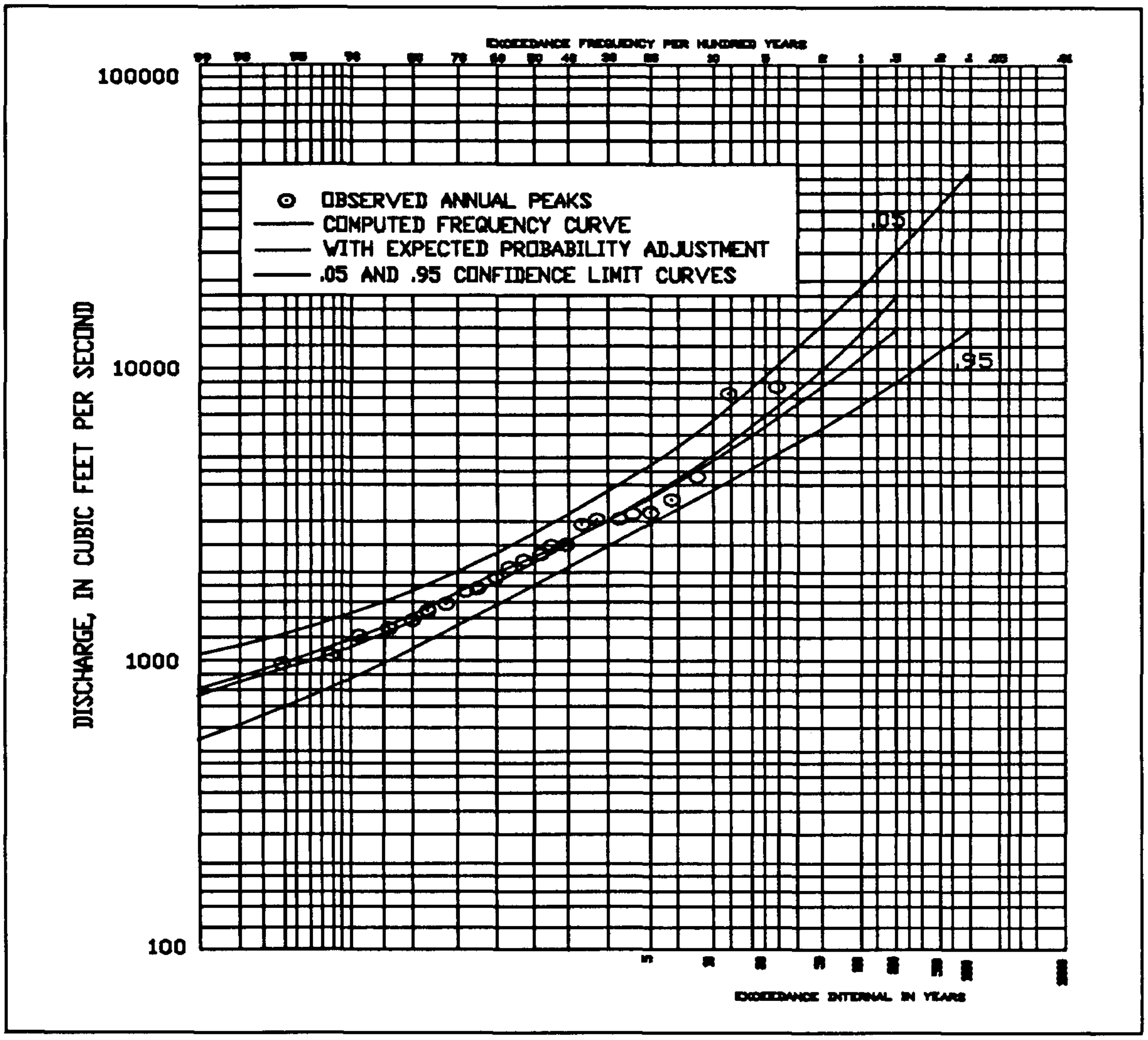

Figure 4-1. Flood frequency analysis by statistical methods

results of ungaged techniques and calibrate and/or verify the hydrologic methods used to estimate discharge-frequency relationship for ungaged areas.

4-3. Simplified Analysis for Ungaged Areas

Ungaged areas are those that have insufficient records to perform a statistical frequency analysis of peak discharge. This usually means no gages at all, but could also include sites that have only a few years of gaged data available. A wide variety of different techniques exist to determine discharge-frequency for ungaged areas. The following descriptions range from the simplest to the most complex.

a. Simplified equations. These methods involve the application of empirical relationships or simple envelope curves to estimate a peak discharge. They are usually applicable for only a certain size of catchment or for a specific type of discharge. Examples include the rational formula (Q = CIA, for very small areas) and the Myers Formula where discharge is function of area, giving the potential maximum possible discharge (McCuen 1989). These methods are easy to apply, but the results are of dubious quality. These techniques are applicable for certain preliminary level studies. Figure 4-2 illustrates the most widely used simplified equation: the rational

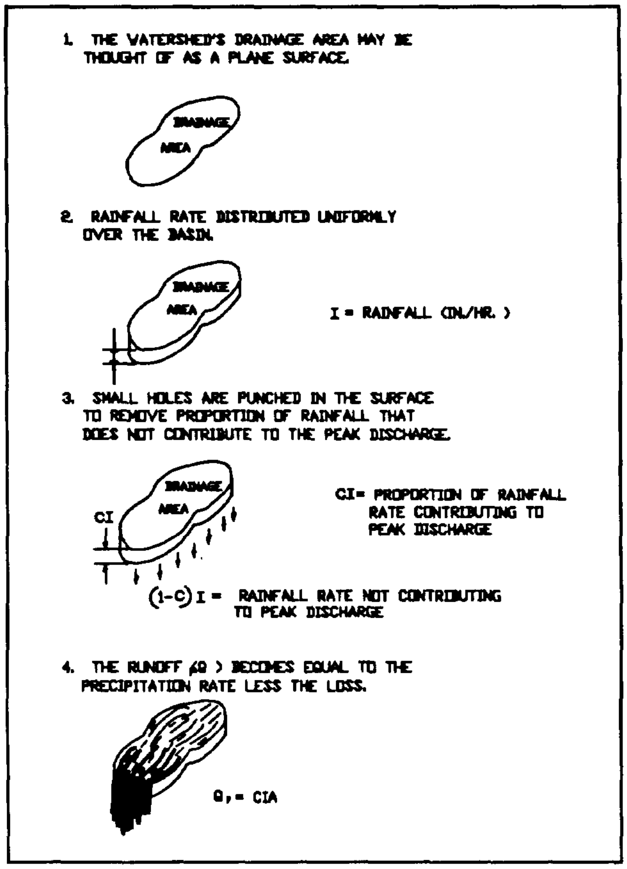

Figure 4-2. Example of simplified equations

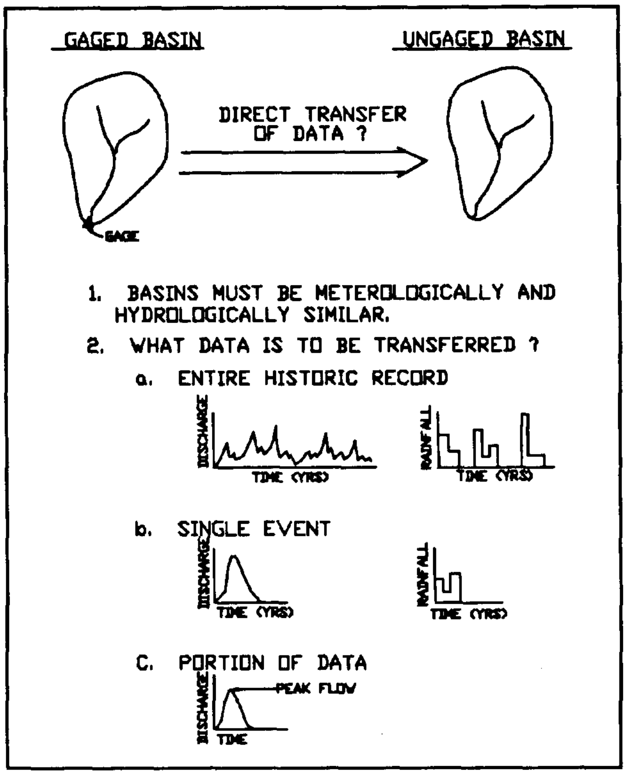

Figure 4-3. Example of transfer techniques

formula. It is still the main method used to determine design discharges for sizing storm sewers.

b. Transfer methods. This technique is also rather simple to apply, but the results are of appreciably better quality. It consists of a simple transfer of measured data from a gaged to an ungaged site, with the data being modified, as necessary, to reflect the conditions at the ungaged site. The modification could be a simple ratio of drainage area of the gaged versus the ungaged site, or be considerably more sophisticated. While discharge, sediment, and other gaged data are transferred to an ungaged site, precipitation data are most commonly transferred. Unless the region is mountainous, precipitation can be readily transferred a moderate distance without adjustment. The transferred data are assumed to be as likely to have occurred on the ungaged portion of the study watershed as on the gaged portion. Figure 4-3 illustrates the use of transfer techniques, which could be valid in any phase of the overall process.

c. Regression analysis.

(1) This method is a more detailed and sophisticated subset of transfer techniques and its development involves considerable work effort. Fortunately, regression analyses for peak discharges have been performed for most portions of the United States, usually by the USGS from gaged data (USGS 1983). Figure 4-4 illustrates the use of regression analysis. This technique develops the desired information (usually peak discharge for given frequencies) from a statistical analysis of long-term gaged records. A regression analysis is then performed linking the calculated peak discharge for each frequency to measurable parameters, like area, slope, stream length, etc. A prediction equation results which allows one to calculate a value for, say, the peak discharge knowing the drainage area and slope of the ungaged watershed. Differences between the discharge calculated with the regression equation and that found with a statistical analysis are called "residuals." These residuals may be mapped and used to adjust the discharge calculated for ungaged catchments. The regression analysis also allows one to estimate the accuracy of the prediction equation results.

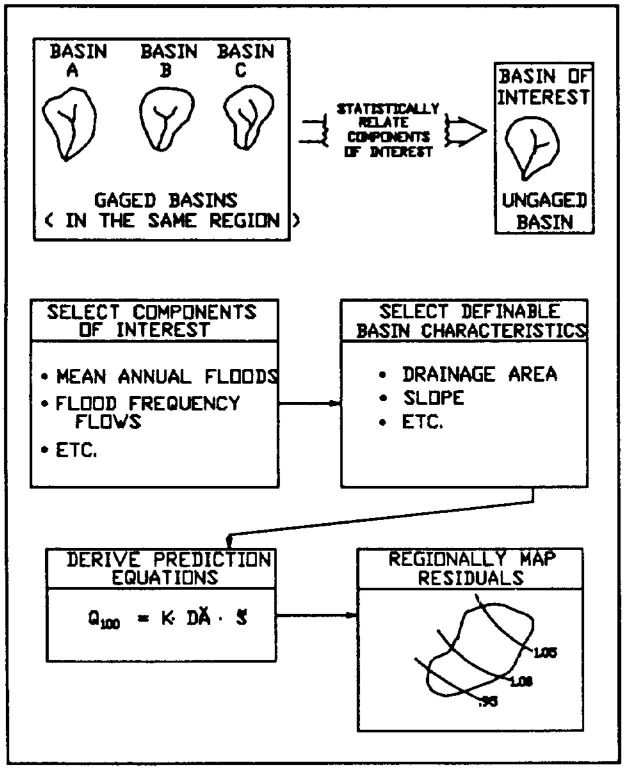

Figure 4-4. Example of regression analysis

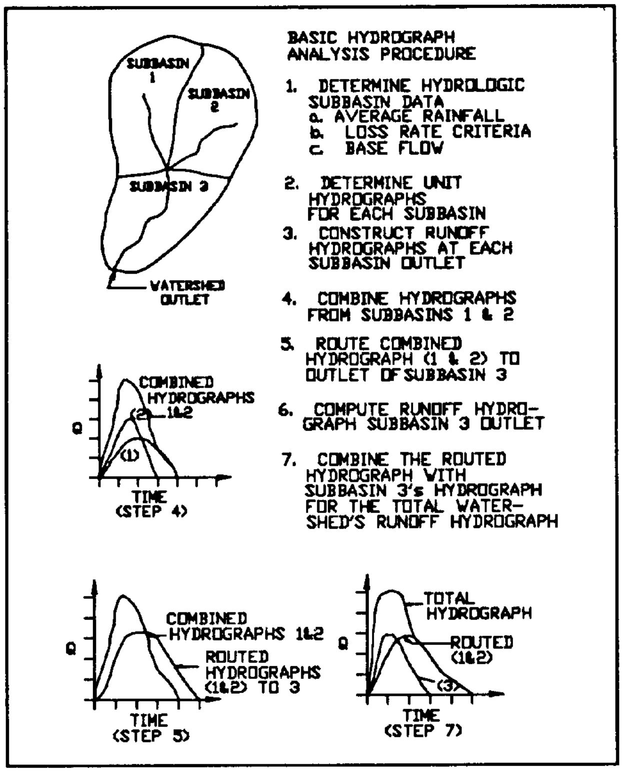

Figure 4-5. Example of hydrologic modeling

(2) Regression techniques are applicable in all phases of a hydrologic study and are valuable in evaluating the reasonableness of peak discharges determined with a hydrologic model. The main drawback to the technique is that only a peak discharge is available and there is no way to estimate how the peak discharge will change if a flood damage reduction structure is placed in the system. This technique is often used where only a peak discharge is needed to estimate flood severity, with flood insurance studies being a typical example. Regression analysis is considered by many to be less accurate in estimating a peak discharge than statistical analysis of gaged data at a site, but more accurate than hydrologic modeling.

4-4. Detailed Analysis for Ungaged Locations

a. The preceding simplified methods can be applied with minimal effort, but all have the same deficiency--how does the flood hydrograph change as it moves through the watershed system and how does the application of flood damage reduction measures affect the flood discharge? The only way in which these questions can be answered lies in detailed hydrologic modeling of the watershed. Figure 4-5 shows a schematic diagram of a typical hydrologic simulation using a model. A hydrologic model is a computer program that simulates the response of a hydrologic system based on meteorologic and physical watershed characteristics. The successful application of a hydrologic model in no easy task and requires knowledge and experience to prepare and operate the model and evaluate the validity of the results.

b. In addition, calibration of the model to some known data is important to gain confidence when applying the model to estimate unknown or rare events. Operation of the model for historical conditions (for calibration and/or verification), and for existing and future conditions (for establishing the severity of the flood problem and the effects of various flood reduction alternatives) is the basis for the overall flood reduction analysis.

c. There are many hydrologic models available to determine runoff hydrographs from a watershed. The procedures by which these models operate vary widely and not all models are applicable to a specific study area. The use of a single- event model versus a continuous simulation model (illustrated in Figure 4-6), actual versus hypothetical (frequency) rainfall, various loss rate functions, modeling of subsurface flow and losses, unit hydrograph versus kenematic wave methods, hydraulic versus

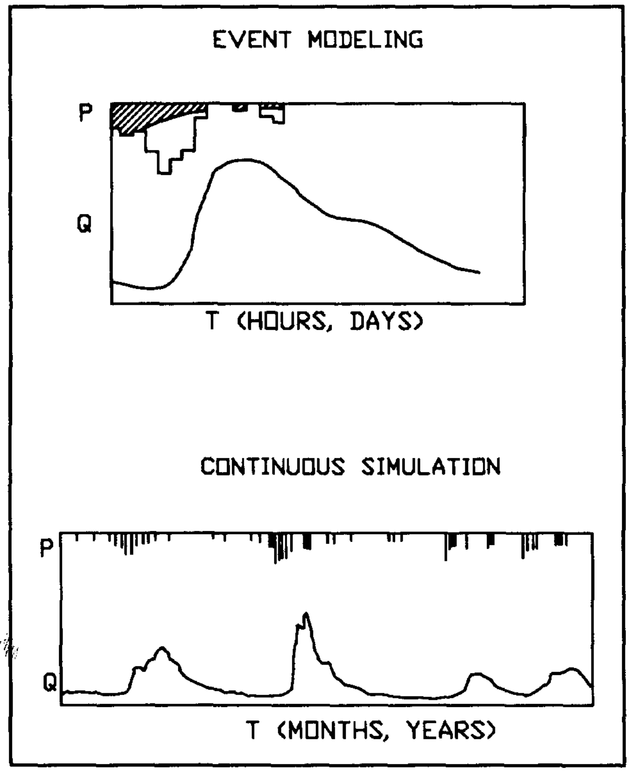

Figure 4-6. Slope event versus a continuous simulation model

kinematic wave methods, hydraulic versus hydrologic routing, etc. are features of the various models. Some models are considerably more detailed and sophisticated than others, requiring a higher level of expertise. The rainfall-runoff process, which these programs model, is presented in Chapter 5.